A COMPARATIVE ANALYSIS OF EOCENE/OLIGOCENE BOUNDARY OSTRACODA FROM SOUTHEASTERN AUSTRALIA AND INDIA WITH RESPECT TO THEIR USEFULNESS AS INDICATORS OF PETROLEUM POTENTIAL

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Summary

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Eocene/Oligocene boundary Ostracoda were analysed from selected wells in the Adelaide Plains Sub-Basin, South Australia and Cambay Basin, India. Source-rock characteristics of the sequences were determined based mainly on ostracode parameters, with some additional information coming from their glauconite and gypsum content. Numerically similar ostracode counts were made for both sets of samples. The parameters studied were: carapace/valves ratio; adults/juveniles ratio; percentage of fragments; percentage of crushed and worn specimens; *Krithe* type; percentage of pyritised specimens.

Results (which concur with exploration results to date) indicate that the Eocene/Oligocene boundary zone sediments have little petroleum potential in South Australia, but high potential in India. This conclusion was largely reinforced when the South Australian borehole Ostracoda were analysed in more detail. Consistent results were also obtained when the same parameters were determined for Ostracoda in outcrop samples collected from Aldinga Bay, South Australia.

KEY WORDS: Ostracoda, petroleum indices, Eocene/Oligocene boundary, South Australia, India.

Introduction

During September-October 1983, one of us (D.K.G.) visited Australia under the aegis of the Australia-India Science and Technology Agreement to study the Tertiary ostracode microfaunas of southeastern Australia for comparison with ostracodes in Indian Tertiary sequences. The senior author (K.G.M.) acted as host for the visit and a co-operative project was initiated.

We soon decided on the Eocene/Oligocene boundary zone because it was well understood both in India and Australia and was known to be important for petroleum exploration in many parts of the world (Pomerol & Premoli-Silva 1986), including India (Guha & Pandey 1980), Australia (Douglas & Ferguson 1976) and China (Hou 1982). Our objective in the comparative study was to determine the respective petroleum potentials of selected Eocene/Oligocene sequences from Australia and India by using ostracode-based parameters developed by Pokorny (1965) and Oertli (1971) and tested recently by Guha (1983), plus some other ostracode (Peypouquet 1979) and sedimentary characteristics regarded by us as pertinent.

It seemed to us that the most pragmatic test of the relevance of the study parameters would be to determine them for wellsite samples. Nevertheless, examination of numerous outcrop samples, including several collected by us both on a brief field excursion during October 1983 to Aldinga Bay, South Australia, made it clear that outcrop material would also yield consistent results. Of the pioneering studies in this methodology that by Pokorny (1965) was based mainly on outcrop samples but included specimens from two boreholes, whereas Oertli (1971) worked exclusively with wellsite samples. In our study, Guha determined the selected parameters for nine samples from the Cambay Well, Cambay Basin, India, while McKenzie determined them for the South Australian Department of Mines and Energy (SADME) Light 1 Well, in the Adelaide Plains Sub-Basin, South Australia; and also for the outcrop samples.

Stratigraphic Summary and Material

South Australia

The Adelaide Plains Sub-Basin is part of the St Vincent Basin (Fig. 1, locality 1). It has been extensively drilled to develop the groundwater resources of the Adelaide region for which it contains two of the principal aquifers. Consequently, the subsurface stratigraphy is well understood (Lindsay 1969, 1985). The Palaeogene sediments include both marine and continental sands, marine limestones and marls. They indicate alternating shallow marine (inshore to outer shelf), transitional and fluvio-lacustrine Palaeogene palaeoenvironments (Lindsay 1969; Cooper 1985; Harris 1985).

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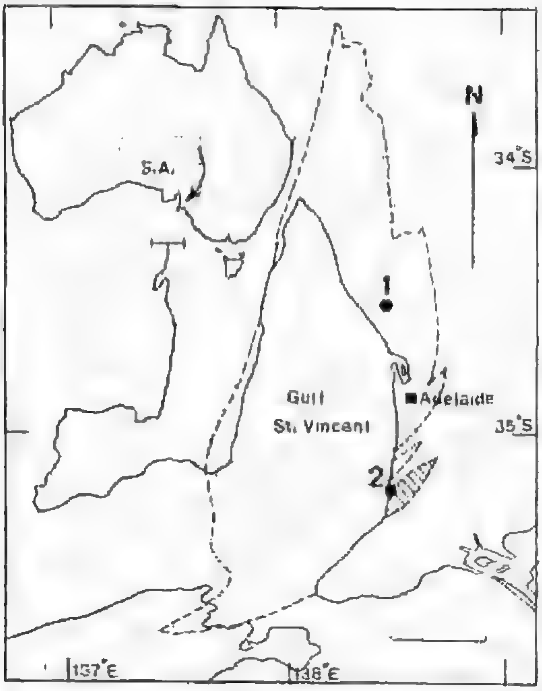

Fig. 1. Locality map of South Australia indicating the locations of: 1, the SADME Light No. 1 Well (about 138° 26'E. Long., 34° 26'S. Lat.); and 2, the Maslin Bay/Aldinga Bay coastal section of the Willunga Embayment (hachured) of the St Vincent Gulf Basin (dashed outline). Scale bar = 20 km. The general location is arrowed on the inset map of Australia.

The SADME Light 1 Well (reference bore 4, core 1 of Lindsay 1969), is particularly noteworthy because it contains, in a cored interval, the Eocene/Oligocene boundary as estimated by Lindsay (1969, 1985) near the base of dark grey, cherty calcareous siltstones forming the "siliceous unit" of Port Willunga Formation — the Ruwarung Member of Cooper (1977, 1979). Below this lie equivalents of the latest Eocene, basal Aldinga Member of Port Willunga Formation, comprising calcareous mudstone, greensand and siltstone; grey-brown speckled green, glauconitic, pyritic, carbonaceous, shelly; in part with very fine quartz sand. Beneath a regressive pebbly sand correlated with Chinaman Gully Formation (Lindsay 1985), Fig. 2), an abbreviated interval equivalent to basal Blanche Point Formation (Lindsay 1968[1]; 1969) rests on, and fills, fractures in probably Proterozoic quartzite (Cornish 1964[2]). Our material includes seven samples supplied by J. M Lindsay (SADME) from the Eocene/Oligocene boundary zone in this well, i.e. from basal Ruwarung Member and uppermost Aldinga Member of Port Willunga Formation.

Total depth of the SADME Light 1 Well was 171.9 m. The seven samples provided to us from core 1 came from the following depths: 139.7–139.8 m; 139.8–140.1 m; 141.1–141.2 m; 142.2–142.3 m; 142.3–142.4 m; 142.75–142.85 m; and 143.2–143.3 m. The Eocene/Oligocene boundary as determined by Lindsay (1969) lies between 141.2 and 142.2 m in this borehole.

Aspects of the regional stratigraphy were described in detail by Cooper (1979) in his study of the Willunga Embayment based on bores and the classic coastal section (Fig. 1, locality 2). Cooper (1979) concludes that the Willunga Embayment was a structurally controlled palaeobay for much of the Cainozoic. Sedimentation in this embayment of the eastern St Vincent Basin began in the Middle Eocene with fluvial sands and intermittent carbonaceous swampy sediments (North Maslin Sands). In the Adelaide Plains Sub-Basin, where SADME Light 1 is located, lignitic Clinton Formation sediments were deposited next, followed by the onset of marine transgression (South Maslin Sands) involving reworking of the earlier fluviatile sands as well as deposition of interdigitating marine and fluvio-lacustrine sandy sediments. Further transgression was marked by high energy bioclastic limestones rich in goethite pellets (Tortachilla Limestone) overlain by glauconitic, spicular and marly clays and silts (Blanche Point Formation) as the transgression attained its maximum level during the Late Eocene. Seasonal upwellings probably characterised this interval. There followed a brief regression (Chinaman Gully Formation) but then marine conditions returned (Port Willunga Formation). The sediments indicate inland to coastal lateral facies variations from non-marine and marginal sands to richly fossiliferous marine carbonates. Such facies persisted from latest Eocene throughout the Oligocene and into the Miocene (Lindsay 1967, 1969, 1985; Cooper 1979). Our material includes four outcrop samples from the Eocene/Oligocene boundary zone (Lindsay 1967; Lindsay & McGowran 1986) in the coastal section at Aldinga Bay (Fig. 1, locality 2).

India

The Cambay Basin (Fig. 2) has India's largest onshore oilfields and is ranked second after the

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[1] Lindsay, J. M. (1968) Palaeontology and stratigraphy. Appendix C, Vol. 1, *In* Northern Adelaide Plains groundwater study to May 1968. 2 vols. Dept of Mines and Energy Report 67/123 (unpubl.)

[2] Cornish, B. E. (1964) Light No. 1 Well completion report. Dept. of Mines report 59/113 (unpubl.).

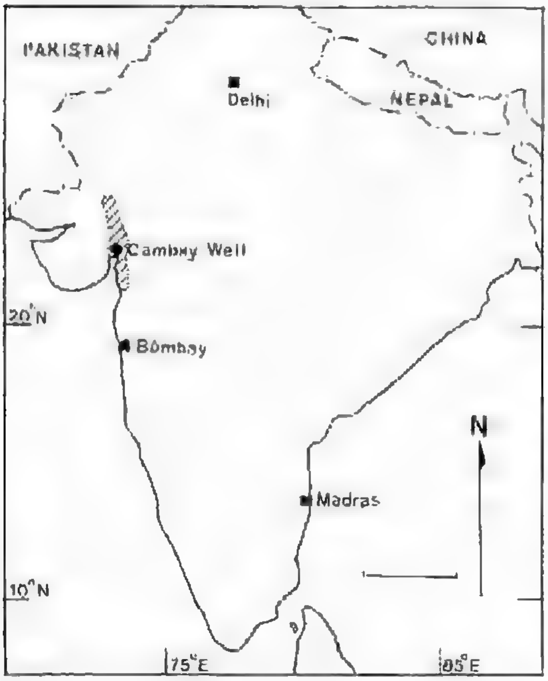

Fig. 2. Locality map of India indicating the Cambay Basin (hachured) and the location of the Cambay Well (72° 36'E Long., 22° 22'N. Lat.). Scale bar = 400 km.

Bombay offshore region in terms of reserves of hydrocarbons (Guha 1983). Not surprisingly, it has been studied in considerable detail and the Palaeogene sequence is confidently correlated and biozoned, based mainly on foraminifera. Palaeoecological analyses indicate alternating shallow marine (inner to outer shelf) and transitional depositional environments for the Basin during the Palaeogene (Guha & Singh 1980).

The Cambay Well is one of several that were drilled to about 2000–3000 m depth with the primary objective of determining the basinal lithostratigraphy. It bottomed in Late Cretaceous basalts of the Deccan Trap. The Eocene/Oligocene boundary in the Cambay area occurs in the Tarapur Shale (Late Eocene-Oligocene) which in this well overlies Cambay Shale (Early-Middle Eocene). The intervening Vaso Formation (Middle-Late Eocene) which is usually unfossiliferous was not identified in the Cambay Well (Guha 1 unpubl.).

The Tarapur Shale is variegated, grey-greenish to light brown, soft to fairly hard and poorly fissile. It is characterised by thick intercalations of quartzose, fine-medium but occasionally coarse-grained sandstone; and, in the Cambay area, by thin intercalations of limestone near its base. The underlying Cambay Shale is dark-coloured, bituminous, moderately hard to fissile, with occasional siltstone beds (Guha & Singh 1980). Guha examined six samples from the Tarapur Shale and three from the Cambay Shale.

Total depth of the Cambay Well was about 2500 m. The 9 samples available to us came from the following depths: 1520 m; 1530 m; 1535 m; 1545 m; 1550 m; 1555 m (Tarapur Shale); and 1570 m; 1585 m; 1605 m (Cambay Shale). The Eocene/Oligocene boundary lies at about 1540 m in this well.

There is considerable support for an Oligocene prospect from the offshore Cambay Basin. Guha & Pandey (1980) in a study based mainly on the Tarapur Offshore Well and incorporating microfaunal, palynological, lithologic and electric log analyses interpreted the interval above the disappearance of *Hantkenina* (Late Eocene foraminiferal datum) as beginning in deeper marine basinal facies and proceeding upwards (above an unconformity/disconformity) into two alternating regressive — estuarine and terrestrial — and transgressive — shallow marine — cycles before the appearance of a characteristic Lower Miocene assemblage. Except for the final (younger) shallow marine transgression there is good evidence for abundant organic matter in euxinic deeper facies and in shallow deltaic and paludal facies also characterised by rapid sedimentation and burial (Guha & Pandey 1980).

Methodology: Ostracode and Other Parameters

Carapaces/Valves ratio

Use of this ratio to yield palaeoecological information was pioneered by Pokorný (1965) in a wide-ranging paper which also dealt with the implications of changing sex ratios and variations in shell ornament. The changing sex ratio parameter has not yet been turned to account for petroleum exploration. On the other hand, many variations in shell ornament are now interpreted in terms of the rhopic factor (Peypouquet, *et al.* 1982) and can be used in suitable facies to suggest presence or absence of upwelling (McKenzie & Peypouquet 1984) which, in turn, is linked to the abundance of organic matter.

Oertli (1971) reviewed Pokorný's work and related the carapaces/valves ratio to potential for the formation of hydrocarbons. In summary, when the ratio is high, rapid sedimentation — which minimises disarticulation of carapaces into separate valves — is indicated; and with sufficiently rapid burial organic matter is not absorbed by mineral particles and so retains the potential for conversion into hydrocarbons.

Adults/Juveniles ratio

In any interpretation of a palaeoenvironment which is based on multispecies assemblages it is essential to separate the autochthonous from the allochthonous faunal elements. Ostracoda are one of the groups in which this separation is achieved rapidly because they molt frequently in progressing to adulthood and because juvenile shells, being also calcareous, are usually preserved. Reyment (1971) discusses in detail the preparation of a life table in order to understand the population dynamics of species. We note that juvenile mortality is always high in his examples based on autochthonous Ostracoda. Therefore, the adults/juveniles ratio should indicate a dominant percentage of juveniles in autochthonous fossil populations, but be heavily biassed towards either adults only or juveniles only for allochthonous taxa. Such biases are interpreted most reasonably as *post mortem* sorting effects. Of course, in some environments, e.g. shorelines, *post mortem* sorting is characteristic for all fossils, autochthonous as well as allochthonous. Thus, to be useful as a positive indicator of petroleum potential, a relatively low adults/juveniles ratio needs to be linked with a high carapaces/valves ratio. This is because the latter indicates rapid sedimentation, which tends to minimise sorting.

Percentage of fragments

This useful parameter is usually ignored by workers making up assemblages slides who tend to pick whole specimens. The percentage of fragments is simple to obtain: two or three counts of 100 specimens, inclusive of all fragmentary ones, being sufficient to estimate it reasonably for any washed sample. Obviously, care must be exercised to avoid damaging specimens during preparation of washings; and the parameter cannot be used conveniently with indurated sediments.

When there is a significant percentage of fragments, it implies a high energy environment. Low percentages indicate low energy environments or else rapid sedimenation.

Crushed or worn specimens

Commonsense suggests that, where autochthonous taxa are concerned, worn or abraded specimens are indicative of high energy environments and slow sedimenation. For allochthons; abrasion is another parameter by which their allochthonous provenance can be interpreted — in the case where autochthonous species are well preserved (not abraded). On the other hand, crushed specimens are associated typically with fine grained muddy and marly offshore sediments. When abundant they are interpreted as indicating considerable compaction pressure, as might be caused, for example, by rapid offshore sedimentation.

Krithe and Parakrithe

The podocopid ostracode genera *Krithe* and *Parakrithe* are used as palaeoecologic indices by Peypouquet (1977, 1979) and others to interpret the palaeohydrology of marine sediments, in particular palaeodepths but also dissolved oxygen (O_2) content, food supply (nutrient) and upwellings. Peypouqet's hypothesis is that the size of the vestibule in the non-calcified inner lamella in *Krithe* and *Parakrithe* is more or less inversely proportional to the dissolved O_2 content of the ambient seawater.

Peypouquet (1977) proposed a physiological explanation based on the known inverse relationship in crustaceans between external dissolved O_2 and organism haemoglobin (HB). In a current review, McKenzie (1986) considered the effects upon HB of several other environmental factors and found that those which were significant — pH, food supply and substrate ferrous iron — would all affect HB synthesis in the same direction as dissolved O_2. This result reinforces the hypothesis. Recently Aladin (1983, 1984) used microcryoscopical techniques to show biochemically that HB regulation in podocopid Ostracoda occurs probably via salt sequestration in the non-calcified membraneous part of the inner lamella. This is precisely the site which Peypouquet (1977, 1979) hypothesised would reflect HB response by *Krithe* and *Parakrithe* to dissolved O_2 variations. The hypothesis has been applied fruitfully in interpreting several palaeoenvironments ranging in age from Maastrichtian to Miocene (Donze *et al.* 1982; Peypouquet *et al.* 1982; McKenzie & Peypouquet 1984).

Pyrite and Gypsum

In oceanic sediments, sulphur is about equally divided between sulphate and sulphide species. The fractionation from sulphate to sulphide (pyritisation) is due to desulfobacterial sulphate reduction. The occurrence of pyritisation in a palaeoenvironment is readily interpreted by reference to its microfauna. For Ostracoda, pyritisation is indicated by a signifient percentage of brownish to blackish valves and carapaces. Occasional specimens glisten with pyrite which is the diagenetic oxidised state of the primary reduced ferrous sulphide that stains/permeates shells to produce the diagnostic coloration

Gypsum is the predominant form of sulphate in marine sediments where it is a component in a global carbon/sulphur redox system that incorporates carbonates, sulphates, sulphides and organic carbon (Garrels & Lerman 1984). In weathered outcrops, its presence is signalled by clumps of relatively large and often fragile gypsum crystals; but in unweathered sediments it can occur as (presumably diagenetic) microspherulites. The latter were recorded, for example, in the Miocene Fyansford Formation, collected at Balcombe Bay, near Mornington, Victoria (McKenzie & Peypouquet 1984); gypsum crystals are common in weathered outcrops at the same locality.

When marine sedimentary sequences carry abundant sulphate/sulphide, their palaeoenvironment is interpreted as having been deoxygenated and strongly reducing in the presence of abundant decaying organic matter and interstitial plus seawater sulphate. This interpretation derives from their sulphide content. Even when diagenesis and weathering have led mainly to formation by oxidative processes of the sulphate gypsum, the stained shells of the microfauna are palimpsests of a depositional reducing palaeoenvironment. A reducing environment, characterised also by rapid sedimentation/burial, inhibits oxidation of organic matter hydrocarbons and, under appropriate depth of burial and temperature conditions, yields petroleum.

Glauconite

Glauconite is an easily recognisable green iron-bearing silicate which is associated with stable outer shelf environments, slow sedimentation, moderately anaerobic conditions on the bottom, and a large amount of decaying organic matter. Often, it occurs together with pyrite. Its significance in source rock interpretation stems from the association with slow, even negative, sedimentation because under such conditions organic matter becomes oxidised and is no longer available to generate hydrocarbons. Glauconite grains are readily transported and sorted commonly forming greensands. Such deposits, with the implication of bottom current action in addition to slow sedimenation, also are counter-indicators in petroleum source rock interpretation.

Results

Tables 1 and 2 provide results of determinations of several of the parameters discussed above for samples from the SADME Light 1 Well, Adelaide Plains Sub-basin, South Australia, and the Cambay Well, Cambay Basin, India, respectively. There were no significant occurrences of crushed or abraded specimens in the counts we made, and gypseous microspherulites were only searched for in the South Australian samples, in which they were uniformly rare.

The results indicate: that similar numbers of specimens were counted for both sets of samples; that the carapace/valves ratio is constantly higher in the Cambay Well as is pyritisation; that the percentage of fragments is much greater and that glauconite is only abundant in SADME Light 1; that the percentage of adults is similar in both sections — varying from 14.5–45% (mean 26.5%) in SADME Light 1, and from 15–44% (mean 33.4%) in the Cambay Well.

The last statistics suggest that we are dealing with assemblages which have approximately similar population dynamics and are predominantly autochthonous (both average about 70% juveniles). Thus, although the two wells are widely separated geographically, they may fairly be compared using ostracodes as indices for source rock characteristics.

The combination of high percentages of carapaces and pyritisation in the Cambay Well section especially in the lower Tarapur Shale and in the Cambay Shale (Table 2) suggests rapid sedimentation offshore combined with a reducing environment in the presence of abundant decaying organic matter. As organic matter decays it uses up available oxygen. This is confirmed by the results from the occasional valves of *Krithe* and *Parakrithe* in the Cambay Well assemblages. In the upper Tarapur Shale samples, above the Eocene/Oligocene boundary, the *Krithe* have small

TABLE 1. *Some parameters of Ostracoda in SADME Light 1 Well, Adelaide Plains Sub-basin, South Australia; recorded in percent except for 4 and 6.* a = abundant; c = common; 1 = carapaces; 2 = adults; 3 = fragments; 4 = glauconite; 5 = pyritisation; 6 = numbers of specimens (the figures in parentheses are the numbers of specimens excluding fragments). The Eocene/Oligocene boundary is indicated at the base of the Ruwarung Member, Port Willunga Formation (PWF).

	1	2	3	4	5	6
Ruwarung Member, PWF	4.6	34.1	45.1	a	12.0	217 (118)
Ruwarung Member, PWF	8.4	14.5	30.0	a	3.5	310 (217)
basal Ruwarung	9.6	22.9	37.3	a	1.5	271 (169)
top Aldina Member, PWF	3.6	26.2	55.7	a	4.0	305 (135)
top Aldinga Member, PWF	2.1	29.1	53.4	a	1.5	285 (133)
top Aldinga Member, PWF	7.0	23.4	39.8	a	1.0	244 (147)
top Aldinga Member, PWF	25.0	45.0	20.0	c	0.0	40 (32)

TABLE 2. *Some parameters of Ostracoda in the Cambay Well, Cambay Basin, India, recorded in percent except for 4 and 6.* r = rare; N.R. = not recorded. 1 = carapaces; 2 = adults; 3 = fragments; 4 = glauconite; 5 = pyritisation; 6 = numbers of specimens (including fragments). The Eocene/Oligocene boundary is indicated in the Tarapur Shale.

	1	2	3	4	5	6
Tarapur Shale	52	30	7	r	32	156
Tarapur Shale	49	36	13	r	37	178
Tarapur Shale	51	43	11	r	23	112
Tarapur Shale	72	37	12	r	68	124
Tarapur Shale	79	26	18	N.R.	65	196
Tarapur Shale	82	15	5	N.R.	71	276
Cambay Shale	100	41	42	N.R.	92	115
Cambay Shale	100	44	28	N.R.	87	132
Cambay Shale	100	29	37	N.R.	95	83

vestibules indicative of a well oxygenated milieu; in the lower Tarapur Shale samples the *Krithe* have very large vestibules which indicates an oxygen poor (or reducing) environment. Unfortunately, no *Krithe* or *Parakrithe* were identified in the three Cambay Shale samples.

On the other hand, in the SADME Light 1 Well section (Table 1) the percentage of carapaces is low in all samples (2.1–9.6%) except the oldest (25%) and the percentage of fragments is significantly high (30.0–55.7%) except in the oldest sample (20%). Further, glauconite is abundant in all samples (it is rare or not recorded in the Cambay Well) except the oldest sample, where it is common; and pyritisation is always rare except in the uppermost sample. These data suggest that marine sedimentation in the SADME Light 1 Well area during Eocene/Oligocene boundary time took place on a well oxygenated outer shelf characterised by slow sedimentation; and relatively constant bottom traction — which produced the large numbers of shell fragments. The occasional *Krithe* which occur in these assemblages confirm the well oxygenated milieu since they have small vestibules.

We conclude that, in terms of the ostracode and other parameters we have studied, the Eocene/Oligocene boundary zone sediments have good petroleum potential in India but little potential in South Australia. This conclusion is consistent with the drilling results. The Adelaide Plains Sub-basin has been extensively drilled as part of a thorough aquifer exploration programme without providing any satisfactory indications of petroleum hydrocarbons. In India, the Cambay Basin is second only to the Bombay Offshore Basin in hydrocarbon reserves and has India's largest onshore oilfields. The source rocks are located in offshore facies immediately below the Eocene/Oligocene boundary and extending downwards into the Middle-Early Eocene sediments.

Detailed Analysis — South Australia

Table 3 provides the results of a more detailed analysis of the SADME Light 1 Well samples. This analysis introduces another parameter, the number of ostracodes per gram of washings picked, as well as breaking down the assemblages into families and analysing these both compositionally and in terms of the parameters already studied for the assemblages as a whole. The prime objective is to enable a more precise palaeoecological interpretation.

All the washings were weighed and then picked for their ostracodes. In some cases, the entire fraction had to be picked to yield a satisfactory count (about 100–200 specimens) but in one instance (the stratigraphically lowest sample) even this method yielded only 40 specimens, including fragments. In most samples, however, Ostracoda were so abundant that only a fraction of the washings needed to be picked. This was the case especially with the two lowest samples from the Ruwarung Member of the Port Willunga Formation. The richest sample was the middle sample of this Ruwarung Member series and the poorest was the lowest Aldinga Member sample.

In terms of ostracode diversity, most of the samples seem very similar, having 19–20 species; but the two lowest (Aldinga Member) samples are less diverse carrying 15 and 11 species respectively. Since diversity can increase significantly with higher counts (Cronin 1984; Whatley & Downing 1983) these diversity results do not warrant more detailed comment.

TABLE 3. *Analysis of ostracode relative abundances in selected families for the SADME Light 1 Well (representing 93.7–99.2% of total ostracodes in the samples examined). Data recorded in percent.* Also recorded are the ostracodes/gm data. A–G = samples examined (as for Table 1), with A = uppermost Ruwarung Member sample to G = lowest Aldinga Member sample, respectively.

Ostracode Family	A	B	C	D	E	F	G
Bythocytheridae	1.8	0.0	4.1	9.5	10.2	0.6	5.0
Cytheruridae	14.8	9.7	7.0	13.1	11.9	9.0	12.5
Xestoleberididae	8.2	12.3	10.0	3.3	3.2	4.5	10.0
Trachyleberididae	46.1	31.9	55.4	43.9	51.9	58.6	45.0
Krithiidae	0.0	2.3	3.0	0.3	0.0	0.4	0.0
Pontocyprididae	8.3	23.9	9.2	11.5	10.5	6.2	20.0
Paracyprididae	0.0	1.3	8.5	0.0	0.0	0.0	0.0
Macrocyprididae	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Bythocyprididae	0.5	2.6	0.0	0.0	0.0	0.0	0.0
Cytherellidae	17.1	9.7	1.1	17.4	10.9	19.7	5.0
% of total ostracodes	97.8	93.7	99.0	99.0	98.6	99.2	92.5
Other Parameters							
Ostracodes/gm (less fragments)	13.9	108.5	52.8	19.3	16.9	15.6	2.0
Ostracodes/gm (including fragments)	25.6	195	84.7	43.6	36.3	23.8	2.5

When the assemblages are broken down into their component families it seems clear that the two richest samples (Ruwarung Member) represent an offshore, even outer shelf environment. Both carry several specimens (7–8) of the genus *Krithe* which is diagnostic for outer shelf and deeper waters. Additionally, the middle Ruwarung Member sample (B, in Table 3) has the family Bythocyprididae (genus *Bythocypris*) which also is typical of deep water facies. This fauna occurs a little higher than the Eocene/Oligocene boundary as determined on foraminifera (Lindsay 1969) thus its palaeoecological interpretation is consistent stratigraphically with what we know of ostracode trends worldwide (Benson 1975) and with the data from Ostracoda of the Willunga Embayment (McKenzie, in Cooper 1979).

The dominant families are the Trachyleberididae, Cytheruridae Xestoleberididae, Pontocyprididae and Cytherellidae. Several other familiees are represented by so few specimens that they have not been included in Table 3, which lists only the 10 most abundant families — representing 93.7% to 99.2% of total ostracode assemblages. These poorly represented families include Loxoconchidae, Cytheridae (genus *Loxocythere*), Eucytheridae (genus *Rotundracythere*), Leptocytheridae, Schizocytheridae (genus *Paijenborchella*). Surprisingly, no specimens of Bairdiidae were identified although this family is virtually ubiquitous in marine facies. The absence of Bairdiidae seems to be a local variation because the family certainly occurs in coeval sediments from the Willunga Embayment (McKenzie 1979).

Clearly, the most abundant family is the Trachyleberididae (Table 3); although it is less abundant (31.9%) in the richest sample (B) than in the other samples (45–58.6%). On this ground, we decided to study trachyleberidid data for the parameters which we used in the preceding more general analysis (Table 4).

TABLE 4. *Some parameters of Trachyleberididae in the SADME Light 1 Well. Data recorded in percent except column 5 which gives actual numbers of specimens analysed.* 1 = carapaces; 2 = adults; 3 = fragments; 4 = pyritisation. Thus, for the Ruwarung Member, PWF there are: 2% carapaces, (98% valves); 30% adults (70% juveniles); 57% fragments; and a quarter of the specimens are pyritised.

	1	2	3	4	5
Ruwarung Member, PWF	2	30	57	25	100
Ruwarung Member, PWF	5	8	40	10	99
basal Ruwarung Member	10	30	40	5	150
top Aldinga Member, PWF	3	30	63	7	134
Aldinga Member, PWF	0	22	63.5	6	148
Aldinga Member, PWF	7	25	40	2.5	143
Aldinga Member, PWF	22	33	33	0	18

We infer, plausibly, that in the uppermost Ruwarung Member sample bottom conditions were reducing for at least part of the time. This suggests that elsewhere in the Eocene/Oligocene of South Australia the Early Oligocene might be a prospective petroliferous zone if the sediments are thicker and also contain high numbers of carapaces, fewer fragments and much less glauconite.

The Eocene/Oligocene boundary zone is already a drilling target off Gippsland, Victoria (Douglas & Ferguson 1976) but with respect to much thicker sections than occur in the St Vincent Basin. Unfortunately, our results from SADME Light 1 offer only slight encouragement for a more intensive exploration of this interval in South Australia

Comparison with Outcrops

During October 1983, we sampled the classic coastal Eocene/Oligocene sections at Maslin Bay and Aldinga Bay, South Australia. Table 5 provides a resume of the data on ostracode parameters and glauconite for samples from this collection.

Although the SADME Light 1 Well (Table 1) was much more closely sampled (over only 1.4 m in the basal Ruwarung Member and only 2.2 m in the upper Aldinga Member), the ostracode data from outcrops correspond rather well. In particular, the percentages of carapaces for the two lowest Aldinga Member samples of SADME Light 1 (located about 1.6–2.0 m below the basal Ruwarung Member sample) are similar in the two outcrop samples from the Aldinga Member (Table 5). Generally, the outcrop samples are less pyritised.

Conclusions

Ostracode parameters, reinforced with evidence from pyrite, gypsum and glauconite can be used to indicate petroleum source rock potential in the enclosing sediments.

1. A high percentage of carapaces indicates rapid burial.
2. Large percentages of adults and juveniles (with juveniles dominant) indicates a mostly autochthonous community.
3. A low percentage of fragments indicates low energy and minimal bottom currents/traction.
4. A high percentage of pyritisation of ostracode carapaces and valves indicates a reducing environment; as do diagenetic pyrite and gypsum in the enclosing sediments.

These several characteristics all indicate good petroleum source rock potential as our extended discussion has made clear.

TABLE 5. *Some parameters of Ostracoda, plus glauconite in outcrops of Aldinga Bay, South Australia, recorded in percent except for 5.* t = trace; 1 = carapaces; 2 = adults; 3 = fragments; 4 = glauconite; 5 = pyritisation; 6 = number of specimens (the figures in parentheses are the numbers of specimens excluding fragments). The Eocene/Oligocene boundary is indicated.

	1	2	3	4	5	6
3 m above base of Ruwarung Member	11.4	39.2	52.8	t	nil	237 (112)
30 cm below top of Aldinga Member	8.9	25.8	50.9	12.5	t	236 (116)
4 m above base of Aldinga Member	25.0	25.0	41.5	t	nil	164 (96)
2 m below top of Gull Rock Member	12.4	15.1	24.6	30	nil	225 (168)

In the exemplar series, ostracode parameters and high pyritisation all confirm the high petroleum source rock potential of the Eocene/Oligocene boundary zone in the Cambay Well, India. On the other hand, in the SADME Light 1 Well, South Australia, and in outcrop samples from South Australia the only positive correlations are with the dominantly autochthonous community characteristic (2, above). In other respects, the Australian samples of the Eocene/Oligocene boundary zone correlate negatively with indications of good petroleum source rock potential. Likewise, glauconite, which is counter-indicative of petroleum source rock potential, is generally common to abundant in the Australian exemplar samples but is not recorded or rare in the Cambay Well.

It is not surprising, therefore, that the Cambay Basin is India's major onshore oilfield in Eocene/Oligocene strata whereas South Australia is non-productive for this interval in the section concerned. Our present methodology appears to be as effective for the Eocene/Oligocene of India and Australia in the areas tested as similar but less detailed methods have proved previously in the Turonian-Coniacian of Bohemia (Pokorny 1965), the Neocomian-Aptian of southwestern France (Oertli 1971), the Maastrichtian-Palaeogene of Mozambique (Oertli 1971) and Bathonian-Tertiary of India (Guha 1983).

Finally, when these parameters are reassessed for samples in which the Ostracoda have been divided into their component families as done (K.G.M.) for the SADME Light 1 Well, the results allow an opportunity to achieve a consistent but more detailed palaeoecological interpretation than could result from the gross data alone.

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References

ALADIN, N. V. (1983) On the displacement of the critical salinity barrier in the Caspian and Aral Seas, the Branchiopoda and Ostracoda taken as examples. *Zool. J.* 62, 689-694. (In Russian).

——— (1984) Salinity adaptations and osmoregulation abilities of Ostracoda from the Black and Azov Seas. *Zool. J.* 63, 185-190. (In Russian).

BENSON, R. H. (1975) The origin of the psychrosphere as recorded in changes of deep-sea ostracode assemblages. *Lethaia* 8, 69-83.

COOPER, B. J. (1977) New and revised stratigraphic nomenclature for the Willunga Embayment. *Q. geol. Notes, geol. Surv. S. Aust.* 64, 2-5.

——— (1979) Eocene to Miocene stratigraphy of the Willunga Embayment. *Rep. Invest., geol. Surv. S. Aust.* 50.

——— (1985) The Cainozoic St Vincent Basin — tectonics, structure, stratigraphy. *In* Lindsay, J. M. (Ed.) "Stratigraphy, palaeontology, malacology; papers in honour of Dr Nell Ludbrook." *Spec. Publ., S. Aust. Dept. Mines and Energy* 5, 35-39

CRONIN, T. M. (1983) Bathyal ostracodes from the Florida-Hatteras slope, the Straits of Florida, and the Blake Plateau. *Mar. Micropaleont.* **8**, 89-119.

DONZE, P., COLIN, J. P., DAMOTTE, R., OERTLI, H. J., PEYPOUQUET, J.-P. & SAID, R. (1982) Les Ostracodes du Campanien terminal a l'Eocene Inferieur de la Coupe du Kef, Tunisie Nord-Occidentale. *Bull. Cent. Rech. Explor. Prod. Elf Aquitanine* **6**, 273-335.

DOUGLAS, J. C. & FERGUSON, J. A. (Eds) (1976) "Geology of Victoria". *Spec. Publ. Geol. Soc. Aust.* **5**.

GARRELS, R. M. & LERMAN, A. (1984) Coupling of the sedimentary sulfur and carbon cycles — an improved model. *Amer. J. Sci.* **284**, 989-1007.

GUHA, D. K. (1983) Use of Mesozoic and Tertiary Indian Ostracoda in oil exploration. pp. 437-441. *In* Maddocks, R. F. (Ed.) "Applications of Ostracoda" (Univ. Houston Geoscience, Houston).

——— & PANDEY, J. (1980) Palaeontology, sedimentation and palaeoenvironment of Oligocene sediments in southwest Gujarat. *J. Palaeont. Soc. Ind.* **23/24**, 156-165.

——— & SINGH, N. P. (1980) Biostratigraphy and palaeoenvironments of the subsurface Paleogene sediments of Cambay-Kathana-Sisva area, Gujarat. *Proc. 3rd. Ind. Geol. Cong. Poona*, 1980, 221-234.

HARRIS, W. K. (1985) Middle to Late Eocene depositional cycles and dinoflagellate zones in southern Australia. *Spec. Publ. S. Aust. Dept. Mines and Energy* **5**, 133-144.

HOU, Y. T. (1982) Cretaceous-Tertiary biostratigraphy and petroleum prospecting of eastern China. *Proc. Symp. Petrol. Geosci. Acad. Sin., Div. Earth Sci., Acad. Sin.*, 97-105.

LINDSAY, J. M. (1967) Foraminifera and stratigraphy of the type section of Port Willunga Beds, Aldinga Bay, South Australia. *Trans. R. Soc. S. Aust.* **91**, 93-110.

——— (1969) Cainozoic foraminifera and stratigraphy of the Adelaide Plains Sub-Basin, South Australia. *Bull. Geol. Surv. S. Aust.* **42**.

——— (1985) Aspects of South Australian Tertiary foraminiferal biostratigraphy, with emphasis on studies of *Massilina* and *Subbotina*. *Spec. Publ., S. Aust. Dept. Mines and Energy* **5**, 187-232.

——— & MCGOWRAN, B (1986) Eocene/Oligocene boundary, Adelaide region, South Australia. *In* Pomerol, C. and Premoli-Silva, I. (Eds) "Terminal Eocene events", pp. 165-173. (Elsevier, Amsterdam).

MCKENZIE, K. G. (1974) Cainozoic Ostracoda of southeastern Australia, with the description of *Hanaiceratina* n. gen. *Geosci. & Man* **6**, 153-182.

——— (1979) Appendix 2. Notes on Ostracoda from Willunga Embayment boreholes WLG 38, WLG 40 and WLG 42. *In* Cooper, B. J. (Ed.) Eocene to Miocene stratigraphy of the Willunga Emabayment. *Rep. Invest., Geol. Surv. S. Aust.* **50**, 90-101.

——— (1986) Ostracoda: new aspects of their biogeography. *In* Heck, K. L., Jr. & Gore, R. H. (Eds) "Crustacean Issues 4, Crustacean Biogeography" (Balkema, Rotterdam).

——— & PEYPOUQUET, J.-P. (1984) Oceanic palaeoenvironment of the Miocene Fyansford Formation from Fossil Beach, near Mornington, Victoria, on the basis of Ostracoda. *Alcheringa* **8**, 291-303.

OERTLI, H. J. (1971) The aspect of Ostracoda faunas — a possible new tool in petroleum prospecting. *In* Oertli, H. J. (Ed.) "Paléoécologie des Ostracodes". *Bull. Cent. Rech. Pau-SNPA* **5** (suppl.), 137-147.

PEYPOUQUET J.-P. (1977) Les Ostracodes et la connaissance des paléomilieux profonds. Application au Cénozoïque de l'Atlantique nord-oriental. These doctorat d'Etat des Sciences, Univ. Bordeaux. 443 pp.

——— (1979) Ostracodes et paléoenvironments. Methodolgie et application aux domaines profonds du Cénozoïque. *Bull. B.R.G.M. (2nd Ser.) Sect. IV* **1**, 3-79.

———, DUCASSE, O., GAYET, J. & PRATVIEL, L. (1980) "Agradation et dégradation" des tests d'Ostracodes. Intérêt pour la connaissance de l'évolution paléohydrologique des domaines margino-littoraux carbonates. *In* "Cristallisation, Déformation, Dissolution des Carbonates" réunion organisée par le Groupe d'Etude des Systèms Carbonates, Univ. Bordeaux, 357-369.

———, DUCASSE, O. & GAYET, J. (1982) Les Ostracodes et la paléohydrologie, paléogéographie et la paléoclimatologie lors de la crise Eocène-Oligocène dans l'Atlantique Nord-Oriental. *In* Gallitelli, E. M. (Ed.) "Palaeontology, essential of Historical Geology". *Bull. Soc. Paleont. Ital.* **20**, 97-121.

POMEROL, C. & PREMOLI-SILVA, (Eds) (1986) "Terminal Eocene events". (Elsevier, Amsterdam).

POKORNY, V. (1965) Some palaeoecological problems in marine ostracode faunas, demonstrated on the Upper Cretaceous ostracodes of Bohemia, Czechoslovakia. *In* Puri, H. S. (Ed.) "Ostracods as Ecological and Palaeoecological Indicators". *Pubbl. Staz. Zool. Napoli* **23** suppl., 462-479.

REYMENT, R. A. (1971) "Introduction to Quantitative Paleoecology". (Elsevier, London).

WHATLEY, R. C. & DOWNING, S. (1983) Middle Miocene Ostracoda from Victoria, Australia. *Rev. esp. Micropaleont.* **15**(3), 347-407.

THE CLASSIFICATION OF THE MITE FAMILIES TROMBELLIDAE AND JOHNSTONIANIDAE AND RELATED GROUPS, WITH THE DESCRIPTION OF A NEW LARVA (ACARINA: TROMBELLIDAE: *NOTHROTROMBIDIUM*) FROM NORTH AMERICA

*BY R. V. SOUTHCOTT**

Summary

Amongst the Trombidioidea an unnamed family group containing Trombellidae, Chyzeriidae and Audyanidae Fam. nov. is recognized; these families are defined and keys provided for the larvae of the families, subfamilies and genera. The Johnstonianidae is examined, and three new subfamilies, Tetrathrombiinae, Pteridopodinae and Ralphaudyninae are established, with *Ralphaudyna* Vercammen-Grandjean *et al.,* 1974 being transferred to the Johnstonianidae.

Ralphaudyna amamiensis Vercammen-Grandjean, Kumada, Newell, Robaux & Suzuki is recorded from a second Japanese location, as an ectoparasite on the gryllacridoid *Tachycines robustus* Ander (Orthoptera, Rhaphidophoridae). Further metric and descriptive data are given for this larval mite.

Nothrotrombidium treati sp. nov., larva (Acarina: Trombellidae) is described from a single specimen found dead on a noctuid moth *Spaelotis clandestina* (Harris) (Lepidoptera: Noctuidae) at Tyringham, Mass., U.S.A.

This is the first record of this genus in North America, previously recorded from Europe and South America, as well as Madeira, in the Atlantic Ocean, and Asia.

KEY WORDS: Taxonomy, *Nothrotrombidium, Ralphaudyna,* larva, North America, Japan, Acarina, Trombidioidea.